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Wireless Sensor Networks Design for Greenhouse Automation

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Abstract*—Greenhouses are usually framed structures covered with transparent material in which crops can be grown under controlled environment. There are some important parameters that should be monitored at a greenhouse in order to achieve good results at the end of the agricultural production. Three of these parameters are temperature, light and humidity. This paper presents a wireless sensor network having several sensor nodes with three commercial sensors to measure the above parameters. To evaluate the network reliability and its ability to detect the microclimate the set up is tested in Indian Greenhouses Pvt.Ltd.'s greenhouse in Talegaon, Maharashtra. Four hours experiment shows that the network stability is fine, the data is consistent with the real environment, power consumption by the network is less, wide range between sensor node and sink node and thus wireless sensor networks can meet the requirements in the applications.

***Index Terms*—Greenhouse, Source node, Sink node, SimpliciTI.**

I. INTRODUCTION

In recent years, the modern large-scale greenhouse has been widely used in the precision agriculture. Greenhouses have a very extensive surface and must be adapt to different plant species in different seasons. In greenhouses, several measurement points are required to trace down the local climate parameters in different parts of the big greenhouse to make the greenhouse automation system work properly.

Traditionally, greenhouse installations have required a great effort to connect and distribute all the sensors and data acquisition systems. These installations need many data and power wires to be distributed along the greenhouses making the system complex and expensive. Cabled measurement points are difficult to relocate once they are installed and the addition of new sensors at different points in the greenhouses is quite limited. The corresponding location of the installations and facilities should be adjusted when the crops experience evolution successions, and sometimes the cables connecting various devices and facilities should also need to be rearranged, which not only causes the increase of the investment costs of the greenhouse and the difficulties of the maintenance, but also may affect plant growth.

Wireless Sensor Networks (WSN) is solution to this problem. WSN is a collection of sensors nodes linked by a wireless medium. The sensor nodes collect information about the greenhouse climate parameters and communicate over a network environment to a computer system which is called a base station. Compared to cable systems, the installation of WSN is fast, cheap and easy. Moreover, it is easy to relocate the measurement points when needed by just moving sensor nodes from one location to another within a communication range. If the greenhouse flora is high and dense, the small and light weight nodes can even be hanged up to the plants' branches. This paper introduces a kind of low cost wireless sensor network, which depends on the closely distributed sensor nodes to collect the environmental information and then sends to base station. It makes a great function in improving managing level in the greenhouse, improving the quality of result in greenhouse. In the conclusion, it plays an important role in social and economical benefits of agricultural production.

II. GREENHOUSE

Natural environment is not always optimum to fulfill the necessary requirements of the crop, resulting significant reduction in productivity and also affect the quality of the produce. By using greenhouse one can control many environmental factors that enable to obtain good quality and more productivity of the crop. Different types of greenhouses are Natural ventilated greenhouse, Fan and pad greenhouse/ greenhouse with evaporative cooling system, Shaded houses, Shadow hall. Fig.1 shows Indian Greenhouses Pvt.Ltd's greenhouse.

Fig. 1: Greenhouse

Advantages of greenhouses are partial protection of plant from high and low temperature, production of quality flowers and vegetables, protection of shade loving plants from sun injury, protection of plant from pest and diseases, protection of plant from wind and hailstorm, less mortality & intensive cultivation throughout the year, efficient use of water, fertilizers, insecticide and pesticides etc and production schedule can be planned as per market need.

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III. HARDWARE OF THE SYSTEM

MICAz (2.4GHz), IEEE802.15.4 [1], CC2420 802.15.4 RF-transceiver [4], CC1100 RF-transceiver [3], CC2430 RF transceiver [6], Tmote Sky module [7], nRF24L01 [8] are used for enabling low-power wireless sensor networks. In this project CC2510 RF transceiver [11] is used as wireless communication module. The advantage of using CC2510 is that it has in built microcontroller. So power consumption is less and its small 6x6 mm package makes it very suited for applications with size limitations.

The system is divided into three parts. The first part is sensor node for data acquisition. Three environmental parameters temperature, humidity and light intensity are sensed by the sensors in every 30 milliseconds. After acquisition sensor node transmits the sensors readings wirelessly through on board PCB antenna. The second part is sink node, which is in the base station receives the data. The third part is the computer that displays the data and stores in database.

A. Sensor node

Sensor node shown in Fig. 2 consists of a sensor module, a processor module, a wireless communication module and a power supply. Sensor module use temperature, humidity and light sensors. Processor module and wireless communication modules use the CC2510 chip. A 9V 2100mA battery is used for power supply. LM1117 [16] is used as voltage regulator.

CC2510 is a 2.4GHz system on chip (SOP) designed for low power application. It contains high performance and low power 8051 microcontroller core, 8/16/32 KB of non volatile program memory, 1/2/4 KB data memory, 7-12 bit ADC and 128-bit AES security coprocessor.

The peripheral components include: Powerful DMA Controller, Power On Reset/Brown-Out Detection, ADC with eight individual input channels, Programmable watchdog timer, Five timers: one general 16-bit timer with DSM mode, two general 8-bit timers, one MAC timer, and one sleep timer, Two programmable USARTs for master/slave SPI or UART operation, 21 configurable general-purpose digital I/O-pins. System clock source is a 24 MHz high Speed crystal oscillator, 2.4 GHz Radio with Baseband Modem, On-chip frequency synthesizer, 2-FSK, GFSK and MSK supported, Small 6x6 mm package makes it very suited for applications with size limitations. Sensors output are converted to digital signal by ADC conversion. These signals are modulated by 24MHz carrier frequency using 2-FSK modulation technique. The transmitter part of CC2510 is based on direct synthesis of the RF frequency. The frequency synthesizer includes a completely on-chip LC Voltage control Oscillator (VCO) and a 90 degrees phase shifter for generating the in-phase (I) and quadrature-phase (Q) LO signals to the down conversion mixers in receive mode. The high speed crystal oscillator generates the reference frequency for the synthesizer, as well as clock for the ADC and the digital part. Sensors data are send in packets wirelessly through folded dipole PCB antenna. CC2510 has following specifications.

Table I: CC2510 specifications [11]

Operating temperature	-40 to 85^{0}C
Operating supply voltage	2.0 to 3.6 V
Frequency range	2400 to 2483.5 MHz
Data rate	1.2 to 500 kBauds (2-FSK)

1) Sensors

a) Humidity sensor

SY-HS-220[13] humidity sensor is used for monitoring humidity inside the greenhouse. It has the following specifications.

Table II: SY-HS-220 specifications [13]

Rated voltage	DC 5.0V
Rated power	≤ 3.0 mA
Operating temperature range	0 to60^{0}C
Operating humidity range	30 to 90% RH
Storage humidity range	Within 95% RH
Storage temperature range	-30 to 85^{0}C
Standard output range	DC 1.980 mV (at 25°C, 60%RH)
Accuracy	± 5% RH (at 25°C, 60%RH)

b) Temperature sensor

LM35 [14] is used as temperature sensor. LM35 is a precision integrated-circuit temperature sensor, whose output voltage is linearly proportional to the Celsius temperature. It has very low self-heating as it draws very less current from power supply, and low output impedance. It has the following specifications.

Table III: LM35 specifications [14]

Accuracy	0.5°C (at +25°C)
Range	−55° to +150°C
Operating Voltage	4 to 30 volts
Current drain	< 60 µA
Self-heating	0.08°C in still air
Output impedance	0.1 Ω for 1 mA load
Output current	10mA
Output voltage	-1V to +6V

c) Light sensor

Light Dependent Resistor (LDR) is used as light sensor. LDR is a resistor whose resistance decreases with increasing incident light intensity. It is made of a high resistance semiconductor. If light falling on the device is of high enough frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electron (and its hole partner) conduct electricity, thereby lowering resistance. Its operating temperature range is -40^{0}C to 75^{0}C.

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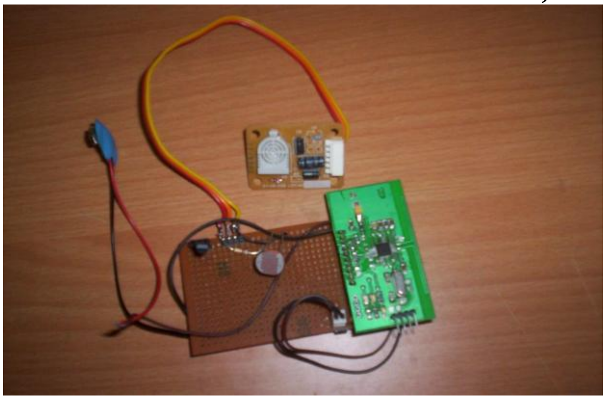

Fig. 2: Sensor node

2) *Antenna Design*

Folded dipole antenna is used for transmitting and receiving sensors data. Features of folded dipole antenna are high input impedance, greater bandwidth, compact, low cost and no external matching components are needed because impedance of folded dipole antenna matches directly with the impedance of the radio. Fig. 3 shows the dimension of antenna.

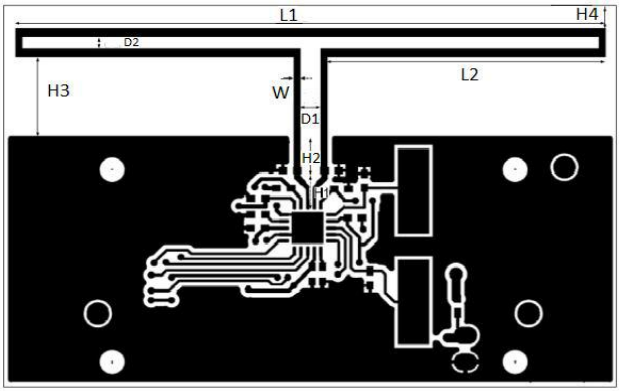

Fig. 3: Antenna dimension [17]

Table IV: Antenna dimension [17]

L1	44.7 mm	H1	2.4 mm
L2	21.0 mm	H2	3.1 mm
D1	1.5 mm	H3	6.0 mm
D2	0.9 mm	H4	2.8 mm

3) *PCB design*

A printed circuit board, or PCB, is used to mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces etched from copper sheets laminated onto a non-conductive substrate. Easily Applicable Graphical Layout Editor (EAGLE) software is used for PCB design.

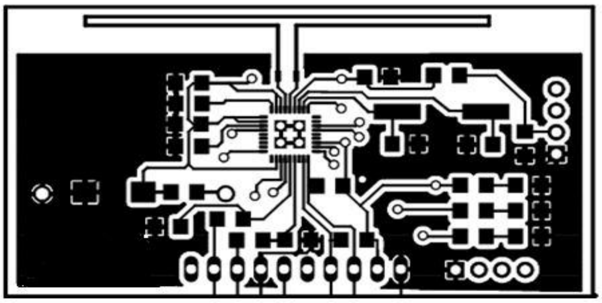

Fig. 4: PCB for source node and sink node

B. *Sink node*

Sink node shown in Fig. 5 consists of CC2510 chip which act as processor and wireless communication module. A 9V 2100mA battery provides power supply. LM1117 is used as voltage regulator. MAX232 [20] is used to provide ±12V for RS232 communication using four 1.0µF external capacitors.

The received RF signal is amplified by the low noise amplifier (LNA) and down converted in quadrature (I and Q) to the intermediate frequency (IF). At IF, the I/Q signals are digitized by the ADCs. Automatic gain control (AGC), fine channel filtering, demodulation bit/packet synchronization are performed digitally. Channel filtering and frequency offset compensation is also performed digitally.

Fig. 5: Sink node

C. *Data storage and display*

There is serial communication between sink node and PC. Tera Term software is used for data storage and display. Real time monitoring is possible by using this software. Historical data are read from database to create different types of charts or curves, which makes it clear and easy for the administrator to comprehend and analyze sensors data.

1) *Tera Term*

Tera Term is an open-source, free, software implemented, and terminal emulator (communications) program. It emulates different types of computer terminals, from DEC VT100 to DEC VT382. It supports telnet, SSH 1 & 2 and serial port connections. It also has a built-in macro scripting language and few other supporting plugins.

IV. SOFTWARE OF THE SYSTEM

CC2510 includes an on-chip debug module which communicates over a two-wire interface. The debug interface allows programming of the on-chip flash. It also provides access to memory and registers contents. The CC Debugger [18] is used for debugging and programming. The PC tools used for these purposes are SmartRF™ Studio from Texas Instrumentation and IAR Embedded Workbench® for 8051 from IAR Systems. SmartRF studio is used for RF testing of radio devices and IAR Embedded Workbench® for 8051 is used for in circuit debugging of system-on-chips. SimpliciTI™ low-power RF protocol is used in the programming.

A. SimpliciTI

SimpliciTI [19] is intended to support customer development of wireless end user devices in environment in which the network support is simple and the customer desires a simple means to do messaging over air. It is a simple low-power RF network protocol aimed at small RF networks. Such networks typically contain battery operated devices which require long battery life, low data rate and low duty cycle and have a limited number of nodes talking directly to each other or through an access point or range extenders. Access point and range extenders provide extra functionality such as store and forward messages. With SimpliciTI the MCU resource requirements are minimal which results in the low system cost. Fig.6 shows SimpliciTI Module components

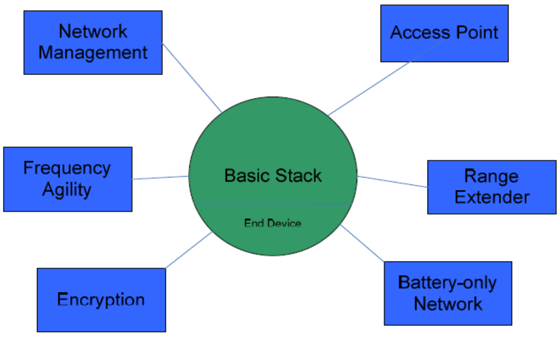

Fig. 6: SimpliciTI Module components [19]

1) Basic Stack

The basic stack will support simple RF messaging with no additional features. As described in the above figure there are modules (features/functions) that can be added to the basic stack in various combinations.

2) Encryption

Encryption is the process of encoding messages (or information) in such a way that eavesdroppers or hackers cannot read it, but that authorized parties can. In an encryption scheme, the message or information (referred to as plaintext) is encrypted using an encryption algorithm, turning it into an unreadable ciphertext .This is usually done with the use of an encryption key, which specifies how the message is to be encoded. An authorized party is able to decode the ciphertext using a decryption algorithm that usually requires a secret decryption key. When encryption is enabled all fields except the address and encryption context fields are encrypted. Though this means that Range Extenders need to decrypt the frame to know whether to repeat it this will prevent rogue devices from storming the network with bogus frames leveraging off the Range Extenders.

3) Frequency agility

This capability allows the network to migrate to a different frequency if the existing frequency is noisy or otherwise compromised. It will be driven by a frequency table that is populated at build time. Devices that can receive packets can detect that they are on the incorrect frequency by not receiving an acknowledgment after sending and resending a frame. The sender then steps through the frequency table until the acknowledgment is received.

4) Network management

This is the domain of the AP (Access points) and consists of functions such as store-and- forward functionality for sleeping devices, encryption key management, and frequency agility management.

5) Access Point

Access points can support End Devices. Access Points will repeat frames but they set the Access Point Sender Type. When replaying a frame the hop count is decremented. Access Points realize Network management functions.

6) Range Extender

Subjected to anti-congestion restrictions enforced by the hop count Range Extenders replay all received packets unless either the range extender itself is the destination of the frame or the Range Extender Sender Type is set in the received frame. APs will also replay frames but since the Access Point Sender Type is set in these frames Range Extenders are permitted to replay frames from APs. When replaying a frame the hop count is decremented.

7) Battery-only network

Battery-only networks do not have APs. In battery-only networks the presumption is that all devices are sleeping devices. Since there is no store-and-forward capability the receipt of frames depends on retransmissions by the sender. The proper balance between the frequency of a receiving device awakening, the length of time the device remains listening, and the frequency with which the sending device retransmits must be in place.

V. EXPERIMENTATION

In order to analyze and optimize system performance, we have conducted an experiment in Indian Greenhouses Pvt.Ltd.'s greenhouse in Talegaon, Maharashtra. Geographical coordinate of the Greenhouse is 18.72°N 73.68°E. In the Greenhouse Gerbera flower is cultivated. Gerbera is a genus of ornamental plants from the sunflower family (Asteraceae).

Fig. 7: Experimental setup

The sensor node is tied to a bamboo which is placed in the middle of the greenhouse. Variation in temperature, humidity and light intensity are measured continuously and sent to th PC located outside the greenhouse. The experiment is conducted for 4 hours from 11.00 am to 3.00 pm for each 30 minutes interval. The range and power consumption of the network is also calculated. Fig. 7 shows the experimental setup of the greenhouse.

VI. RESULTS

Fig. 8 presents the temperature in ^{o}C obtained during 4 hours monitoring inside the greenhouse.

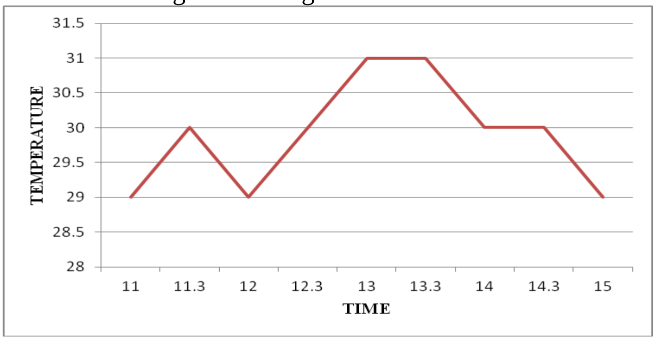

Fig. 8: Temperature measurement results

Fig.9 represents the humidity variation obtained during 4 hours monitoring inside the greenhouse.

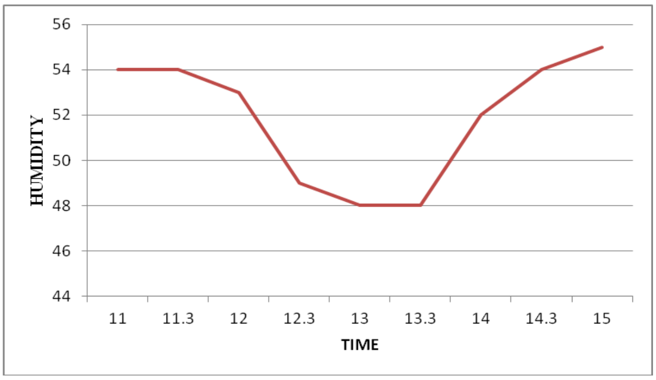

Fig. 9: Relative humidity measurement results

Fig. 10: represents variation of light intensity obtained during 4 hours monitoring inside the greenhouse.

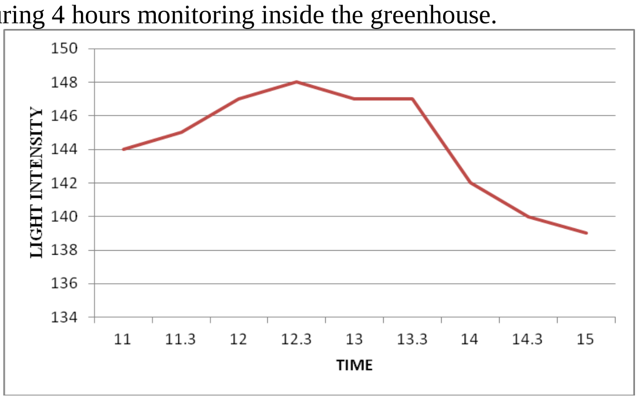

Fig. 10: Light intensity measurement results

The maximal communication range, 36 meters was figured out in individual test where the distance between the sink node and the sensor node inside the greenhouse was increased until the connection was lost. We also observed that the reliable range in terms of tolerable packet loss was approximately 32 meters. With 9V, 2100mAhr battery the sensor node works up to 25 hours.

VII. CONCLUSION

This paper reports on an agricultural application study of wireless sensor networks in greenhouses. From experimental test, it has been confirmed that the system can efficiently capture greenhouse environmental parameters, including temperature, humidity, and light intensity and it shows normal communication between source and sink node and fine network stability. It also obtains strong adaptability, good confidentiality and high reliability. The only additional costs occur when the sensor nodes run out of batteries and the batteries need to be charged or replaced. So we will develop greenhouse wireless sensor network monitoring system design based on solar energy. The sensor nodes receive the solar energy and supply it to the wireless sensor network. The design will consume less energy and cost effective.

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